Effect of Leaf Defoliation on Assimilate Partitioning in Maize (Zea mays L.) Hybrid SC. 704

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Abstract
To investigate the sink-source relationship in maize (hybrid SC704) a field experiment was conducted at experimental field of College of Agriculture, Shiraz University during 2007 growing season. The experiment was a randomized complete block design with four replications. Treatments included defoliation intensity (remove of 0, 50% and 100% of leaves) and defoliation time (silking stage and defoliation of leaves at 10, 20 and 30 days after silking). The results showed that the highest ear dry weight, ear length, number of grains per ear, number of grain in row, 1000 grain weight and grain yield, were obtained from 50% defoliation at 30 days after half silking. However, delay in defoliation was associated with enhanced mentioned parameters. In contrast, the lowest values for all traits measured in this study were related to 100% defoliation at half silking. This finding indicated that assimilates mobilization from stem to the grains. In addition, the highest and lowest stem dry weights were obtained from control and 100% leaves defoliation at 30 days after silking, respectively. Overally speaking, results showed that complete and 50% leaf defoliation in maize plants after half silking had negative impact on grain yield and its components. Increase in defoliation intensity was associated with more reduction in grain yield.

Key words: Silking, Corn, Yield, 1000 grain weight

Introduction
Yield improvement in breeding of field crops has been accompanied with better dry matter partitioning to the grains. Therefore, approaches related to grain yield improvement has included increase of partitioning to the grain, delay in leaf senescence and increased grain filling period. Carbohydrates used in grain are provided by current photosynthesis, temporary transfer of reserved in stems, leaves, ear and shelling of the maize (Emam and Seghatoleslami, 1999). Defoliation or leaf damage, such as that associated with hail, frost, wind, crop protection chemicals, and insects, can affect pollination and subsequent grain production. At early-season defoliation can delay anthesis and silking (Haagenson et al., 2003, Echarte et al., 2006, Singh and Nair, 1975), shorten the duration of pollen shed (Carcova et al., 2003), and reduce the total amount of pollen produced (Echarte et al., 2006).
Vasilas and Seif (1985a) found that defoliation at the 14-leaf stage had a differential effect on anthesis and pollen shed by inbreds. Changing source-sink ratio in fertile maize may strongly affect post-anthesis stem reserves. For instance, shoot dry weight and its reserves are decreased due to defoliation after tasseling (Edmeased and Lafitte, 1993). When the source size is decreased, the dynamic materials are remobilized from other organs including the stem towards the sinks. This process is continued till these reserves are decreased or their further transfer is not possible (Mostafavi and Cross, 1990). In an experiment, elimination of a number of corn leaves increased the mobilization of assimilates to some extent, so that the need of all sinks was met by the remaining leaves (Jones et al., 1996). Assimilates partitioning to the grains is affected by both source and the sink size and is regulated by vascular connections, capacity of non-grain tissue reserve and requirements of nitrogen by the tissues. Experimental evidences indicated that transport in phloem may be performed to a far distance although every sink is normally supplied with the source close to it. After pollination, the source-sink relationship is the most important economic factor affecting corn production, i.e. grain growth becomes dominant and existence of carbohydrates at a threshold level is essential for formation of fertile maize (Emam and Seghatoleslami, 2005). In order to identify the mechanisms of controlling grain filling, manipulation of the source power and the sink size has been studied in several researches. Some evidences have indicated that the maximum grain yield has been accompanied with a balance between the source and the sink (Tollenaar et al., 1992). During a farm research, Emam and Tadayon (1999) reported that it seems that by thinning the two upper leaves of the maize in single cross 704 maize hybrid, it is possible to increase the density of corn plant to about 11.11 plants per m², so that the grain yield is not decreased and some forage is also produced since the thinning causes better penetration of light into the shaded part of the maize and increase lower leaves' efficiency as well as decrease of competition between the maize and the tassel for assimilates, and in general, decrease of inter- and intra-plant competition. Defoliation treatments have showed to decrease assimilates availability at during grain filling (Echarte et al., 2006). Defoliation treatments imposed when the number of grains had been established reduced the source/sink ratio and resulted in a sharp decrease in stem soluble carbohydrates (Westgate and Boyer, 1985). Defoliation treatments decreased grain yields due to a reduction in the number of kernels per ear, as well as mean kernel weight (Rodrigo et al., 2007).

By studying the effect of changing source-sink ratio on grain dry weight in three crops of wheat, corn and soybean, (Borras et al., 2004) reported that limitation of yield in these three crops is due to sink-limitation. With regard to corn plant, it has been found that dry weight of grains is seriously decreased by decrease in availability of assimilates during the grain filling period; however, increased availability of assimilates per seed might shows no significant response. These results indicated that corn plant is a sink-limited crop in most farming conditions. Haagenson et al. (2003) reported that October defoliation of alfalfa reduced the protein content of the root, while defoliation in December increased the root sugar content.
They argued that defoliation of alfalfa increased nitrogen and carbohydrates retransfer from the root to the stem. Defoliation of wheat at late tillering stage has led to 22% increase in water use efficiency (Westgate et al., 2004). It seems that decreased leaf area at some developmental stages of the plant would not decrease the yield due to lack of source limitation in wheat or in other words disability of the seeds in receiving all the produced assimilates (Borras et al., 2004). Mangen et al. (2005) came to the conclusion that defoliation of corn reduces grain yield while it has no effect on seed oil content. Defoliation intensification in corn plant reduced the grain yield and consequently the simultaneous reduction of leaf and grain yield leads to decrease in yield (Lauer et al., 2004). In general, kernel number is the main determinant of sink capacity (Westgate et al., 2004, Thomas and Sadras, 2001). Borras et al. (2002) argued that decrease in number of kernels per ear and consequently decreased grain yield in corn plant in 50% and 100% defoliation treatments are due to decreased current photosynthesis, and decrease of number of leaves has a direct relation with decrease of current photosynthesis. Until present, maize source-sink ratio during grain filling has been classically estimated as biomass produced per kernel during the effective grain filling period (Dordas, 2009, Otthman and Welch, 1989, Borras et al., 2002). Regarding the fact that Fars province is the supplier of more than half of the country’s corn, any research on improvement of grain yield of this crop by physiological manipulations would have great significance. Since it seems that the number of leaves in corn plants grown in this province is high, the objective of present research was to study the possibility of more assimilates partitioning to the grains by decreasing the number of leaves.

**Materials and Methods**

This study has been conducted at the research field of the colleague of Agriculture, Shiraz University located at 18 km north-east of Shiraz during spring and summer 2007. The research field had an altitude of 1810 m above the mean sea level, with its longitude of 52:35 and its latitude of 29:40. The farm was planted on June, 25 using KSC 704 maize hybrid seed. The experimental design was a completely randomized block with four replications. The treatments consisted of the time of defoliation in four levels, included from the time of appearance of mid-silking (when the average length of appeared tassels was about 2-3 centimeters) with 10-days intervals, and intensity in three defoliation levels inclusive removing of zero, 50 and 100 percent of the leaves in each plant. The soil was silty sand with pH= 7.8 and saturated soil extracts electrical conductivity of 2.41 ds.m$^{-1}$. The land preparation operations included: plowing, disking, leveling and then delineation of the experimental plots. Each plot included five 5-m rows with 75 cm apart. The plants were 12.5 cm apart on each row. Seeds were planted manually in 5cm depth. Defoliation treatment was done on September 2nd manually using clipper. Plots were hand weeded regularly, and irrigated every eleven days by siphon. Soil physical and chemical characteristics (0 to 30 cm depth) were determined before the experiment. Nitrogen and phosphorous manure requirements calculated based on soil test, were supplied by application of 400 and 200 kg per hectare urea and ammonium phosphate fertilizers, respectively.
Half of the nitrogen was applied at planting time and the other half at 6-leaf stage. All the phosphorous fertilizer was applied before sowing. In order to determine the dry weights, the samples were kept in oven at 70°C for 48 hours. SAS program was used for data processing and for diagrams depicted using Excel. Means were compared using Duncan’s multiple range test (P<0.05).

Results and discussion

Stem dry weight

Stem dry weight was significantly affected by defoliation intensity at the time of final harvest; so the maximum stem dry weight (99.70 g) was obtained from control, while the minimum stem dry weight (55.78 g) was belonged to 100% defoliation treatment (Table 1). In the similar study, Emam and Seghatoleslami (1999) showed that complete defoliation causes a significant decrease in final stem dry weight and this indicates the increase of remobilization of reserved assimilates from the stem to the ear. The maximum stem dry weight was obtained from defoliation at silking and 10 days after mid-silking although they had no significant difference with each other. However, the stem dry weight in defoliation treatment at mid-silking (78.94 g) was higher than other treatments (Table 1). Changes in the dry weight of maize also suggested that dry matter stored before flowering contributes little to the grains (Mangen et al., 2005). Maximum stem dry weight in final harvest was obtained from the control treatment (100 g) which had a significant difference with other treatments (Table 2). In contrast, the minimum stem dry weight was allocated to 100% defoliation treatment performed at 30 days after mid-silking (50 g). According to the results, a decreasing trend was observed in the stem dry weight due to increase in defoliation intensity and delay in defoliation (Table 2).

Ear dry weight

Defoliation intensity treatment had a significant effect on ear dry weight, so the maximum ear dry weight (137.85 g) was observed in the control treatment and the minimum ear dry weight (43.78 g) was found in 100% defoliation treatment (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Effects of intensity and time of defoliation on shoot dry weight, ear dry weight, number of grains per ear, 1000-grain weight and grain yield.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intensity of defoliation</strong></td>
</tr>
<tr>
<td>0 %</td>
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<tr>
<td>50 %</td>
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<tr>
<td>100 %</td>
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<tr>
<td><strong>Time of defoliation</strong></td>
</tr>
<tr>
<td>Silking</td>
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<tr>
<td>Defoliation at 10 days after silking</td>
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<td>Defoliation at 20 days after silking</td>
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<td>Defoliation at 30 days after silking</td>
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Means with similar letter in each column are not significantly different (DMRT p<0.05).
Table 2. Interactive effects of defoliation intensity and time on shoot dry weight, ear dry weight, number of grains per ear, 1000 grain weight and grain yield.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Shoot dry weight (g.plant&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Ear dry weight (g.ear&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Grains per ear</th>
<th>1000 Grain weight (g)</th>
<th>Grain yield (kg.ha&lt;sup&gt;-1&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td>138.85&lt;sup&gt;a&lt;/sup&gt;</td>
<td>625&lt;sup&gt;a&lt;/sup&gt;</td>
<td>220&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12000&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Defoliation of 50% leaves at silking stage</td>
<td>85&lt;sup&gt;b&lt;/sup&gt;</td>
<td>75&lt;sup&gt;c&lt;/sup&gt;</td>
<td>375&lt;sup&gt;e&lt;/sup&gt;</td>
<td>180&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6100&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Defoliation of 50% leaves at 10 days after silking</td>
<td>77&lt;sup&gt;c&lt;/sup&gt;</td>
<td>110&lt;sup&gt;b&lt;/sup&gt;</td>
<td>470&lt;sup&gt;c&lt;/sup&gt;</td>
<td>195&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9500&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Defoliation of 50% leaves at 20 days after silking</td>
<td>72&lt;sup&gt;d&lt;/sup&gt;</td>
<td>110&lt;sup&gt;b&lt;/sup&gt;</td>
<td>500&lt;sup&gt;b&lt;/sup&gt;</td>
<td>210&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9550&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Defoliation of 50% leaves at 30 days after silking</td>
<td>56&lt;sup&gt;f&lt;/sup&gt;</td>
<td>140.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>625&lt;sup&gt;a&lt;/sup&gt;</td>
<td>220&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11500&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Defoliation of 100% leaves at silking stage</td>
<td>62&lt;sup&gt;e&lt;/sup&gt;</td>
<td>18&lt;sup&gt;e&lt;/sup&gt;</td>
<td>220&lt;sup&gt;h&lt;/sup&gt;</td>
<td>90&lt;sup&gt;g&lt;/sup&gt;</td>
<td>500&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Defoliation of 100% leaves at 10 days after silking</td>
<td>60&lt;sup&gt;e&lt;/sup&gt;</td>
<td>37&lt;sup&gt;d&lt;/sup&gt;</td>
<td>250&lt;sup&gt;g&lt;/sup&gt;</td>
<td>130&lt;sup&gt;f&lt;/sup&gt;</td>
<td>3120&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>Defoliation of 100% leaves at 20 days after silking</td>
<td>52&lt;sup&gt;e&lt;/sup&gt;</td>
<td>77&lt;sup&gt;e&lt;/sup&gt;</td>
<td>335&lt;sup&gt;f&lt;/sup&gt;</td>
<td>170&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5950&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Defoliation of 100% leaves at 30 days after silking</td>
<td>50&lt;sup&gt;e&lt;/sup&gt;</td>
<td>77&lt;sup&gt;e&lt;/sup&gt;</td>
<td>455&lt;sup&gt;d&lt;/sup&gt;</td>
<td>175&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6700&lt;sup&gt;e&lt;/sup&gt;</td>
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</table>

Means with similar letter in each column are not significantly different (DMRT p<0.05).

Ear dry weight was significantly different among the defoliation treatments performed 10, 20 and 30 days after mid-silking. The maximum and minimum values were obtained from defoliation at 30 days after mid-silking (106.89 g) and mid-silking (69.36 g), respectively (Table 1). The reports of other researchers (Andrade et al., 2005, Arduini et al., 2006) also indicated that source capacity during grain filling could influence grain weight at physiological maturity. Plant biomass partitioning to the developing ear (ear growth rate/total plant growth rate around flowering) differs depending on the plant growth rate, and also among genotypes (Borras et al., 2004). It is currently understood that kernel number is a function of the rate of biomass accumulation at the ear level around flowering (Andrade et al., 2005, Borras and Otegui, 2001, Echarte et al., 2006). The results of interaction effects showed that maximum ear dry weight at final harvest was obtained from 50% defoliation treatment at 30 days after mid-silking (140.65 g) with no significant difference with the control treatment (138.85 g) (Table 2). In contrast, the minimum ear dry weight was found at 100% defoliation treatment at mid-silking which was significantly different with other treatments (Table 2).

**Number of grains per ear**

The results showed that the number of grains per ear was significantly affected by defoliation intensity at the time of final harvest, so that the maximum number of grains per ear was obtained from 0% defoliation treatment and the minimum number of grains per ear was found in 100% defoliation treatment (Table 1). Comparison of different defoliation treatments showed that the maximum and minimum numbers of grains per ear were obtained from defoliation treatments at 30 days after mid-silking and silking stage, respectively (Table 1). The interactive effect of defoliation time and intensity indicated that maximum number of grains per ear was found from control as well as
50% defoliation 30 days after silking (Table 2). In contrast, the minimum number of grains per ear was obtained from 100% defoliation treatment at mid-silking (Table 2).

**1000-grain weight**

The maximum 1000-grain weight (220.50 g) was obtained from control (i.e. 0% defoliation) and its minimum (150.15 g) was found in 100% defoliation treatment. Defoliation at 10 days after mid-silking resulted in the lowest mean kernel weight (186.08 g; Table 1). According to the interaction effects, the maximum 1000 grain weight was achieved from control as well as 50% defoliation at 30 days after mid-silking (Table 2). In contrast, the minimum 1000 grain weight was obtained from 100% defoliation at mid-silking (Table 2). According to Lauer *et al.* (2004), assimilate availability can affect mean kernel weight only at early grain development stage, so that increasing availability assimilate at later stages of grain filling would not affect 1000 grain weight. In present investigation defoliation 30 days after mid-silking did not affect mean kernel weight, which in accordance with the finding of Lauer *et al.* (2004), Borras *et al.* (2004) and Emam and Seghatoleslami (1999). Recently, Rodrigo *et al.* (2007) have also argued in a same manner.

**Grain yield**

Grain yield was significantly affected by defoliation intensity (Duncan 5%), so that the maximum grain yield (12730.7 kg.ha⁻¹) was obtained from the control treatment. The minimum grain yield (4819.8 kg.ha⁻¹) was achieved at 100% defoliation treatment. In addition, defoliation time had also a significant effect on grain yield and the maximum grain yield was obtained from defoliation at 30 days after mid-silking (Table 1). Emam and Seghatoleslami (1999) reported that complete defoliation of corn at 20 days after full tasseling caused a decrease of 52% in grain. Echarte *et al.* (2006) argued that the reason for decrease in grain yield was reduced current photosynthesis upon defoliation. Maximum grain yield at final harvest was obtained from the control treatment, which had no significant difference with defoliation of 50% leaves at 30 days after mid-silking (Table 2). In contrast, the minimum grain yield was found in 100% defoliation at mid-silking stage (Table 2). According to the results, delay in defoliation was associated with an increasing trend in grain yield; however, the grain yield was reduced upon increased defoliation intensity. These results are in accordance with the findings of Emam (2012), who reported that any stress occurred later in the season, would less affect the grain yield.

**Conclusion**

Delay in defoliation reduced the negative effect of defoliation stress on grain yield and its components. Defoliation at mid-silking sharply decreased current photosynthesis and hence yield components. It appeared that remobilization was stimulated by intensification of defoliation; stem dry weight was found to be decreased by increased defoliation intensity as a result of remobilization of assimilates from the stem to the ear. Overall, maximum grain yield was achieved from control treatment as well as 50% defoliation at the 30 days after mid-silking.
References


